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INTEGRATION OF IMPROVEMENTS IN SILVER-CADMIUM ELECTROCHEMICAL CELLS

CONTRACT No. NAS 5-10238
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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1 INTRODUCTION AND SUMMARY

During the investigation under contracts NAS 5-3452 and NAS 5-9106, we found that sealed silver-cadmium cells must be designed specifically to meet current density and ampere-hour requirements for a particular orbital regime. Since this contract states that the cells are to be optimized for the 1.5 , 8 , and 24 hour orbits, three different designs were chosen after a thorough review of the past contractual efforts on silver-cadmium cells which were sponsored by the National Aeronautics and Space Administration.

Specifically, the design improvements which will be incorporated in the cells are:

1. Control of the silver electrode density.
2. Use of non-woven polyamide on the positive and negative electrodes.
3. Control of the uniformity of separator materials.
4. Use of "ruggedized" (Teflon and fibers) negative electrodes.
5. Control of cell electrolyte level.
6. Optimum electrolyte concentration.
7. Third electrodes for gas recombination.

Other improvements in the design of silver-cadmium cells which show limited or transitory effects are: lead (Pb) plating of the silver electrode and grid, and use of stabistors for charge control. These items will be discussed in the text which follows, but will not be used in the final cell designs.

This report also includes the finalized cell designs, cell and assembly drawings, separator composition, process parameters (for "ruggedized" CdO electrodes), and description and manufacturers of cell components. A complete review of past NASA contracts on sealed silver-cadmium cells is not presented in detail in the discussion. Parts of this review are only presented in conjunction with the various selected design improvements which will be incorporated in the cells.

2 RECOMMENDED DESIGN IMPROVEMENTS

As a basis for the final cell designs, we will first discuss the improvements which will be utilized in the construction of sealed silver-cadmium cells for Phase II of this contract.

2.1 Control Of The Silver Electrode Density

Work done under contract NAS 5-3452 (Quarterly Reports Nos. 3 and 4) has shown that improvement in the material utilization of the silver electrode at high rates has been achieved by decreasing the plate density from 4.8 to 4.2 g/cc. Figure 1 shows the effect of plate density on silver utilization at 600, 1200 and 2000 cycles on the 100 minute orbit at 35% depth of discharge. It can be seen that the efficiency of silver at 4.2 g/cc, based on ampere-hours per cubic centimeter of plate, is about 16% better than silver at 4.8 g/cc. Also, 4.2 g/cc is the optimum density based on ampere-hour per gram utilization of silver. Reducing the silver density to 3.6 g/cc results in an electrode which initially yields superior AH/g utilization, but its capacity decays with subsequent cycling of the electrodes because of the poor mechanical stability.

It should be pointed out that no significant improvement was obtained by decreasing the silver density in cells which were cycled on the 24 hour orbital regime. This is probably because the positive electrode is not limited by diffusion of hydroxyl ions during a low rate charge.

For the design of the cells to meet the 1.5 hour orbit requirements, we will therefore use silver electrodes fabricated to a density of 4.2 g/cc. The density of the silver electrodes for the 8 and 24 hour orbit cells will be set at 4.4 g/cc and 4.6 g/cc, respectively.

2.2 Use Of Non-woven Polyamide On The Positive and Negative Electrodes

Studies carried out under contracts NAS 5-3452 and NAS 5-9106 have shown that the use of non-woven polyamides on the positive electrode (such as Pellon 2506K), improves the high rate charge efficiency of the silver electrode in comparison with woven nylon. In addition, when Pellon is incorporated on the negative electrodes, all free electrolyte can be removed without degradation in cell performance. The gas recombination rates of sealed cells have been found to improve when free electrolyte is removed. For example, at 45 psia the initial oxygen recombination rate for cells containing non-woven polyamide on the positive and negative with no free electrolyte was about 3 ma/in^2. The value for cells containing a normal quantity of KOH was about 0.9 ma/in^2. It should be noted that although removing all the free electrolyte from cells constructed with woven nylon interseparator improves oxygen recombination, approximately a 30% loss in initial cell capacity also results. Therefore this technique cannot be used with cells constructed with woven nylon.

The use of non-woven fabrics on both the positive and negative electrode has also been thoroughly studied on a prolonged float type regime. The tests were carried out in 5 cell batteries for float periods up to 16 months. These studies have shown that:

(1) Removal of free electrolyte from cells made with Pellon 2506K on the positives and negatives eliminates undesirable pressure rises (resulting from cell unbalance). This is because the rate of oxygen recombination is substantially increased. The increase in the rate of oxygen reaction with cadmium keeps the negative state of charge low, thus preventing hydrogen evolution.

(2) Periodic deep discharges have shown that capacity maintenance for batteries with non-woven nylon and without free electrolyte was excellent.

Based on the above results the final cell designs will contain Pellon non-woven polyamide both on the positive and negative electrodes.

2.3 Control Of The Uniformity Of Separator Materials

Control of the swelling of separator materials, in practice, cannot easily be achieved. The non-woven polyamide as received from the Pellon Corp. is about 5 ± 1.5 mils, also the variation in swelling of

C-19 is 3.2 ± 0.2 mils. Because of these facts it will be necessary to randomly check the separators from each specific lot from which cells will be fabricated. To accomplish this, the materials will be maintained under a mechanical pressure of 4 psi during the soaking period and the percent expansion measured. If the total separator expansion is less than the design value, plastic spacers could be positioned on each face of the cell to make up the unexpanded space. If the expansion is greater than the design value, the end negative plates could be made slightly thinner to maintain uniform cell pressure.

The need for spacers or more space is not thought likely since a preselected lot of separator will be used. The rolls of separator to be used for these cells will be selected from a lot with the desired characteristics. The uniformity will be checked by the following tests:

1) Visual inspection
   a) Color
   b) Holes and/or weak spots.
2) Thickness
   a) Dry - minimum of 1 reading per running foot
   b) Wet - minimum of 20 samples selected in a random pattern.
   c) Controlled expansion (at 4 psi)

2.4 Use Of "Ruggedized" (Teflon And Fibers) Negative Electrodes

During our evaluation of Teflon additives to the negative to improve gas recombination, it was found that the plates' plastic properties also added considerably to its mechanical strength. However, without any additional binders the plates developed severe cracks during cycling. It was therefore necessary to provide the electrodes with additional strength by the incorporation of a fibrous matrix. The function of the plastic binder thus became to interlock the cadmium oxide particles around nylon fibers; it was found that this combination greatly increased the durability of the electrodes. Cadmium oxide electrodes with a rigid structure were prepared by the addition of 0.5 - 2.5% Teflon and 0.10 - 0.20% nylon fibers (by weight) to the cadmium oxide.

It was found that the higher loadings of Teflon greatly increased the amount of pressure necessary to compress the mixture on the conductive grid. Also, during high rate charging (i.e. 60 - 100 ma/in^2) the polarization on these negatives is quite high, which necessitates a higher cut-off voltage for the cell. The negative electrodes fabricated with only 1% Teflon do not require high pressure to compress and the polarization characteristics are only slightly higher than electrodes without Teflon during high rate charging.

Ruggedized cadmium electrodes which contained 2.5% Teflon which were cycled on a deep discharge regime at I_C = 83 ma/in^2 and I_D = 150 ma/in^2 showed almost 90% of original capacity retention after 400 cycles. The standard sponge electrodes however, had decayed to about 50% of original output. The specific values for the ruggedized and sponge negatives were 0.27 AH/g and 0.16 AH/g, respectively. BET surface area measurements showed that the ruggedized electrode actually increased in area from 6.2 m^2/g to 6.55 m^2/g after cycling, while the control electrode area decreased from 5.95 m^2/g to 4.6 m^2/g after the same number of cycles.

Following this experiment a 5 ampere-hour, 5-cell battery was constructed which included in its design plastic-bound, fibrous negatives, along with low density silver electrodes, one Pellon 2506K on the positive and negative and 5 turns of C-19 main separator. This battery, along with one of a more standard design, was also evaluated on a deep cycle regime. It was found that after 420 cycles the ruggedized design was giving 5.5 AH while the control had dropped to about 4 AH, or a loss in capacity of about 40% based on initial output. The improved utilization of the ruggedized negative electrodes may be due in part to the fact that the wet-proofing binder decreases the KOH electrolyte retention of the plate by about 18%. It is obvious then, that the quantity of oxidized soluble separator debris which is known to decrease Cd utilization is also substantially reduced. The plastic binder-fiber-combination also prevents cracking of the electrode which is probably due to densification and shrinking of the metal with cycling. This shrinkage has also been found to decrease the utilization of cadmium in untreated plates.

Because of the slightly higher resistance of the ruggedized plates, the amount of Teflon in the cells for the 1,5 hour orbit will be reduced to 0.5%. For the 8 and 24 hour orbital cells 1.0% Teflon will be used in the negative mix.

2.5 Control Of Cell Electrolyte Level

Control of the electrolyte quantity (rather than electrolyte level) in a sealed cell is necessary to insure maximum oxygen recombination with cadmium. We have reviewed the work that Electric Storage Battery Co. has done on bellows control of electrolyte levels (Contract NAS 5-3813). This approach obviously decreases the energy density (Wh/lb) of the cell. Moreover, with the use of third electrodes bibulous interseparator material, and initial electrolyte adjustment, maximum gas recombination is obtained without extremely careful electrolyte level control during subsequent cycling.

For the three cell designs therefore, electrolyte removal need involve only that quantity which is necessary to expose the maximum area of the third electrode for recombination.

2.6 Optimum Electrolyte Concentration

The choice of the optimum electrolyte concentration has been shown to depend for the most part on temperature extremes which are imposed on the battery. To some degree it also depends upon the orbital regime requirements. Since the temperature and capacity requirements of this contract are 0°C to 40°C and 40% depth of discharge respectively, the electrolyte concentration will be between 40 and 45% KOH.

The electrolyte concentration for the 1.5 and 8 hour orbit cells will be 40% KOH, since these cells will be charged at fairly high rates. This concentration will be used because the electrical resistivity is somewhat lower than 45% KOH, which will result in better high rate charge acceptance and low temperature performance. The results were discussed in the First Quarterly Progress Report - NAS 5-9106 (Research and Development of the Silver-Cadmium Couple for Space Application).

The electrolyte concentration for the 24 hour orbit cell will be 44% KOH. It has been shown that the mode of failure of the long orbit cells is by silver penetration of the separator (NAS 5-3452 - Fourth Quarterly and Final Reports). This concentration of KOH will increase the useful battery life by decreasing the rate of silver attack on the separator as compared to 40% KOH on the 24 hour orbit regime.

2.7 Use Of Third Electrodes For Gas Recombination

The use of third electrodes for gas recombination has been extensively studied at the General Electric Advanced Technology Laboratories under contract AF 33 (615) 2615 (1966). Third or auxiliary electrodes are required whenever the oxygen recombination rate of the unassisted Cd electrode is exceeded during overcharge. The maximum continuous overcharge rate for the Cd electrodes in an 11 AH cell is between 10-20 ma at room temperature. However, we have found that the recombination is increased by 300-500 ma. for each in^2 of third electrode included in the cell. The third electrodes are positioned on the edge of the cell pack in order to preferentially avoid discharging on on the end Cd electrodes during overcharge. This preferential discharge would reduce cell capacity in inverse proportion to the number of Cd electrodes present.

It has further been found that the cell separator system must be specifically designed to accommodate a third electrode. In a standard cell design, electrolyte expelled from the positive compartment during overcharge will increase the level in the negative compartment and thus submerge the 3rd electrode. This leads to a decrease in the recombination rate even though pressure is increasing. If the overall electrolyte quantity is reduced, performance suffers. However, this problem can be minimized by increasing the electrolyte quantity and storage space available in the positive compartment. As already discussed, this is accomplished by decreasing the positive electrode density and increasing the amount of non-woven polyamide.

The proper catalyst loading for third electrodes for use in silver-cadmium cells is approximately 50-60 mg.Pt/in^2. This amount of Pt is required to prevent loss of activity due to organic poisoning. We have cycled sealed Ag-Cd cells with 3rd. electrodes containing 50 mg Pt/in^2 for 4 months at temperatures up to 140°F with no reduction in activity. These cells are still cycling. The work carried out at the G.E. Laboratories also indicates that third electrodes are desirable for maintaining cell "balance" during cycling.

In view of the above data third electrodes will be incorporated in each of the three cell designs to be delivered to NASA. The exact size of the 3rd. electrode will be determined by the specific orbital regime and the expected overcharge rates.

3 OTHER CELL IMPROVEMENTS

3.1 Lead (Pb) Plating Of The Silver Electrode And Grid

It has been found that silver electrodes which are plated with Pb initially show improved utilization down to -10°C. Lead plating of the silver expanded metal collector also prevents voltage dip at low temperature, but does not improve silver utilization. However, cycle life tests of these cells on the 100 minute orbit regime show that the beneficial effects derived from Pb disappear after 500-700 shallow cycles (35% depth of discharge). This is probably due to oxidation and dissolution of lead from the electrodes.

It is evident that improvements in voltage and capacity are obtained initially when silver electrodes are treated with Pb. However, for the most part these properties are transitory. These advantages, therefore, do not warrant the incorporation of lead in the positive electrodes.

3.2 Use Of Stabistors For Charge Control

The use of a stabistor (forward junction diode) for individual cell charge control has been extensively studied at Mallory under Contract AF 33 (615) - 2491. In this method the charging current is shunted around the cell when a set voltage is reached. While this technique works exceptionally well for nickel-cadmium cells, a problem exists for silver-cadmium cells in matching the stabistor's characteristics to the cell under control, particularly the temperature coefficients of both. It has been found that even with a stabistor present Ag-Cd cells are capable of gassing at a rate exceeding the recombination rate. This can occur when the cutoff or bypass voltage for the stabistor is set to allow the cell to charge rapidly and completely. In addition, stabistor devices as presently manufactured subject the cell to a continuous drain on stand, so that the cell must be continuously charged. The present state-of-the-art of stabistors therefore do not warrant their inclusion into the cells for this procurement.

4 FINAL CELL DESIGNS

Based on the literature review of past NASA contractual efforts and the previous technical discussion, the following cell design have been selected for the 1.5, 8, and 24 hour orbit regimes. (See Sections 5 and 6 for a complete disclosure of general design parameters, including electrode and separator composition, process parameters and material suppliers).

4.1 Design For 1.5 hr. Orbit

Due to the high rate of charge required for the 1.5 hr. orbit, this cell was designed with the maximum number of plates compatible with a minimum initial capacity of 11 ampere-hours. As mentioned in the technical discussion, the density of the silver powder was kept low (4.2 g/cc) to achieve optimum silver utilization and the amount of Teflon in the negative electrodes is 0.5%, to reduce polarization. Complete design parameters are as follows. (See notes at the end of Section 4.3):

a) Positive Electrodes

Number per cell	:	10
Size	:	1-9/16"W x 1-5/8" h x 0.0195" ± 0.001" th
Area	:	2.51 in^2 (with die cut corners, 3/16" R)
Total plate area	:	50.2 in^2
Composition	:	100% silver powder (1)
Silver powder per plate	:	3.30 g.
Silver powder per cell	:	33.0 g.
Silver powder density	:	4.20 g/cc
Grid	:	expanded silver strip No. 5 Ag 15-1 (2)
Leads	:	1 silver tab. 3/32" W x 0.004" th.
Weight (leads not included)	:	3.60 ± 0.09 g.
Lead insulator	:	Polyethylene tubing

b) Negative Electrodes

Number per cell	:	11 (9 full and 2 half end plates)
Size (Full plates	:	1-9/16" W x 1-5/8" h x 0.045" ± 0.002" th.
Size (Half plates	:	1-9/16" W x 1-5/8" h x 0.024" ± 0.002" th.
Composition (by weight)	:	(94.35% cadmium oxide powder + (5% silver powder + 0.5% Teflon + (0.15% nylon fibers

Cadmium per plate	:	4.95 g (2.47 g in half plates)
Cadmium per cell	:	49.5 g.
Cadmium density	:	2.90 g/cc
Grid	:	expanded silver strip No.5 Ag 15-1 (2)
Leads	:	2 silver wires, 0.016" dia.
Weight (including 3" long leads and aldex cross)	:	Full plates: 6.52 ± 0.22 g.
	:	Half plates: 3.52 ± 0.12 g.
Cadmium to silver weight ratio	:	1.50
Lead insulators	:	Polyethylene tubing

c) Separator System

Wrapping method		:	Normal "U" wrap (3)
Positive Interseparator	(type	:	1 bag of P-3
	(size	:	1-21/32"W x 1-3/4"h (10 pcs)
Main separator	(type	:	5 turns of C-19
	(size	:	17-3/16" x 4" (5 pcs)
Negative Separator	(type	:	1 "U" of P-3
	(size	:	1-19/32" x 3-7/8" (11 pcs)

d) Third Electrodes

Type	:	American Cyanamid type AB-6X LD-213-461-3B (with hydrophobic film)
Number	:	1 per cell
Position	:	Perpendicular to (+) and (-) plates
Size	:	1-5/8" h x 1.1" w.
Leads	:	2 silver wires, 0.016" dia.

Separation from cell pack	:	Pellon P-12, 2 layers.
Separation from cell wall	:	(Vexar plastic netting 15 ADS 129 (NL (mat'l. polyethylene)
Supporting grid material	:	Silver mesh screen, gold plated.

e) Electrolyte

Type	:	40% solution of potassium hydroxide in water.
Density	:	1.399 g/cc
Amount	:	(4)

4.2 Design For 8 hr. Orbit

This cell was designed with 2 pairs of electrodes less than the cell for the 1.5 hr. orbit. The extra room gained by the corresponding reduction in the number of separator "U"s was used to slightly increase the amount of active materials and to substitute P-5, a heavier sheet of non-woven polyamide, for P-3. The density of silver powder was increased to 4.4 g/cc, and the Teflon content in the negative electrodes to 1%, since the rate of charge required for the 8 hr. orbit is relatively low, minimizing electrolyte diffusion and irrigation problems.

Design parameters are as follows (refer to paragraph 4.1 for parameters not listed below):

a) Positive Electrodes

Number per cell	:	8
Thickness	:	0.024" ± 0.001"
Total plate area	:	40.15 in^2
Silver powder per plate	:	4.25 g
Silver powder per cell	:	34.0 g.
Silver powder density	:	4.40 g/cc
Grid	:	expanded silver strip No. 5 Ag 15-1
Weight (leads not included)	:	4.55 ± 0.11 g.

b) Negative Electrodes

Number per cell	:	9 (7 full and 2 half end plates)
Thickness (Full plates	:	0.060" ± 0.002"
Thickness (Half plates	:	0.032" ± 0.002"
Composition (by weight)	:	(93.85% cadmium oxide powder (+ 5% silver powder + 0.5% Teflon (+ 0.15% nylon fibers
Cadmium per plate	:	6.38 g (3.19 g in half plates)
Cadmium per cell	:	51.0 g
Cadmium density	:	2.80 g/cc
Weight (including 3" long wires and aldex cross)	:	Full plates: 7.98 - 8.56 g. Half plates: 4.25 - 4.55 g.
Cadmium to silver weight ratio:	:	1.50

c) Separator System

Positive interseparator	: (Type:	1 bag of P-5
	(Size:	1-21/32"w x 1-3/4" h (8 pcs)
Main separator	: (Type:	5 turns of C-19
	(Size:	17-3/16" x 4" (4 pcs)
Negative separator	: (Type:	1 "U" of P-5
	(Size:	1-19/32" x 3-7/8" (9 pcs)

d) Third Electrodes (See Section 4.1)

e) Electrolyte

Type: : 40% solution of potassium hydroxide in water.

4.3 Design for 24 hour Orbit

In consideration of the low rates of charge (and discharge) required for the 24 hour orbit, a minimum number of electrodes was used, and to take advantage of the extra space available in the cell pack, the amount of active materials was increased (15% over the 1.5 hr. design) and an additional layer of C-19 was added to the separator system, to provide for the long wet life expected from the cell. A heavy grid was incorporated to the positive electrodes to compensate for the loss of conductivity due to the slow activation of the solid silver grid over a large number of low rate charges.

Design parameters are as follows (refer to Section 4.1 for parameters not listed below).

a) Positive Electrodes

Number per cell	:	6
Thickness	:	0.035" ± 0.001"
Total plate area	:	30.1 in^2
Silver powder per plate	:	6.34 g.
Silver powder per cell	:	38.0 g.
Silver powder density	:	4.60 g/cc
Grid	:	expanded silver strip No. 5 Ag 8-4/0
Weight (leads not included)	:	7.18 ± 0.18 g.

b) Negative Electrodes

Number per cell	:	7 (5 full and 2 half end plates)
Thickness (Full plates	:	0.087" ± 0.002"
Thickness (Half plates	:	0.045" ± 0.002"
Composition (by weight)	:	(93.85% cadmium oxide powder (+ 5% silver powder + 1% Teflon (+ 0.15% nylon fibers
Cadmium per plate	:	9.67 g. (4.83 g. in half plates)
Cadmium per cell	:	58.0 g.
Cadmium density	:	2.80 g/cc
Weight (including 3" long leads and aldex cross)	:	(Full plates: 12.32 ± 0.43 g. ((Half plates: 6.42 ± 0.22 g.
Cadmium to silver weight ratio:	:	1.52

c) Separator System

Positive interseparator	: (Type:	1 bag of P-5
	(Size:	1-21/32" W x 1-3/4" h (6 pcs)
Main separator	: (Type:	6 turns of C-19
	(Size:	$20\frac{1}{2}$" x 4" (3 pcs)
Negative separator	: (Type:	1 "U" of P-5
	(Size:	1-19/32" x 3-7/8" (7 pcs)

d) Third Electrodes (See Section 4.1)

e) Electrolyte

Type : 45% solution of potassium hydroxide in water.

Notes

1) It is common practice to include 5 to 10% of cadmium oxide powder in the positive electrodes of silver-cadmium cells, as a protection against gassing, in the event of an overdischarge. However, for the shallow cycling regime intended for the present cells, overdischarge is not possible, except (a) in case of cell failure (which is not dependent on the presence or absence of the cadmium oxide) or (b) near the end of the useful life of the cells (at this point the cadmium oxide may add a few cycles to the life of a battery).

For the above reasons, and since the addition of cadmium oxide would reduce the amount of active silver in the cells, it was decided not to include it in these cells for the present program.

2) The designations for the expanded metal strips are code numbers assigned by the Exmet Corp., our supplier for the product.

3) See Section 5 for a description of the wrapping method.

4) The correct amount of electrolyte for all designs will be determined upon reception of the first prototype cells produced by YEC.

5 GENERAL DESIGN PARAMETERS

5.1 Positive Electrodes.

5.1.1 Manufacturing Process.

The positive electrodes are cut to size, by means of a blanking die, from strips continuously produced by a rolling mill. The rolling process consists of the following operations: (1) transfer of the silver powder from a storage hopper to a conveyor, (2) leveling of the powder to uniform thickness and weight per unit area by the successive action of two adjustable doctor blades, (3) covering of the moving layer of powder by a sheet of expanded silver metal (exmet), (4) pressing of the powder and exmet to uniform thickness with a roller, (5) exposing the moving strip to sintering temperature of an electric furnace and (6) air cooling of the sintered strip.

During the rolling operation, the finished strip is regularly checked for weight and thickness as it comes out of the rolling mill and adjustments are made immediately, whenever necessary. Each individual plate is also checked for weight before spot-welding the leads, which is the final operation in the manufacture of the plate. After spot-welding, the electrodes are checked for thickness, including the lead area.

5.1.2 Materials.

5.1.2.1 Silver Powder

A) Physical Properties

a) Apparent density: 1.4 to 1.9 g/cc.

b) Average particle size: 2.0 - 4.0 microns.

B) Mechanical composition: 99.9% minimum silver (dry basis); max. of 0.3% (as Ag) of soluble silver salts.

Electrical properties: The powder must have an electrical utilization of 2.6 grams per ampere-hour or better.

5.1.2.2 Expanded silver grid (exmet).

The grid is made from solid silver sheet, by means of a special machine tool which punches and expands the metal, to form a perforated sheet, with diamond shaped holes. The thickness of the original sheet, the strand width of the finished grid and the pattern of the openings may be varied according to specifications. The finished grid has a silver content greater than 99.9%.

5.2 <u>Negative Electrodes</u>

5.2.1 Manufacturing Process.

The negative mix, consisting of cadmium oxide powder, silver powder, Teflon suspension and nylon fibers is prepared, taking special precautions to obtain a perfect dispersion of the fibers. The mix is sintered at 360°C for approximately 10 minutes. The weight of mix required for the manufacture of each electrode is transferred to the cavity of a mold, previously lined with a cross of aldex paper, and containing the grid, with the leads spot-welded. The mix is uniformly spread into the mold and covered with the protruding section of the aldex cross, thus completely wrapping the plate. A plunger, fitting into the cavity with minimum clearance is placed on top and enough pressure is applied to reduce the plate to the required thickness. After releasing the pressure and removing the mold, the plate is ready for use.

5.2.2 Materials.

5.2.2.1 Cadmium oxide powder.

A) Physical properties.

a) Free flowing powder.

b) Particle size: 0.95-2.50 microns

c) Bulk density: 0.30 - 0.90 g/cc

B) Chemical composition:

CdO	: 99.5% minimum
Zn	: 0.002% max.
Sn, Ag, Ni, Fe, In, Cu, Co, Tl	: 0.0005% max. (each)
Sb, Bi	: 0.001% max.
Pb	: 0.01% max

5.2.2.2 Silver powder : See 5.1.2.1

5.2.2.3 Teflon (trademark for Dupont's polytetrafluoroethylene resin) -

A suspension of 60% Teflon in water is used. This suspension is obtained directly from the manufacturer.

5.2.2.4 Nylon fibers

The nylon fibers are obtained from small cuts of woven nylon separator material, by means of a blender. Special care must be taken to use only very small size fibers, to avoid mechanical difficulties in the preparation of the mix and construction of the electrodes.

5.3 Third Electrodes

A detailed account of the size and location of the third electrodes is given in Section 4.1. The theoretical and practical reasons that justify their use are discussed in Section 2.7.

As mentioned in Section 4.1, the electrodes are covered with a hydrophobic film at the liquid-gas interface side. The function of the film (a grafted plastic coating) is to protect the electrode from inactivation caused by flooding.

5.4 Separator System.

The separator system consists of the following items:

a) A positive interseparator (non-woven polyamide fibers).

b) Main separator (several layers of C-19).

c) Negative interseparator (non-woven polyamide fibers).

The thickness of the polyamide fibers and the number of layers of C-19 varies for each particular design. (See Section 4).

5.4.1 Wrapping Method.

The wrapping of the cell electrodes is performed as follows:

a) The positive interseparator is prefabricated in the form of a bag, heat sealed at the bottom and sides and open on top.

b) The positive electrode is slipped into the bag.

c) A pair of positive electrodes (with bags) are placed, with their bottoms facing each other, on a piece of main separator, previously cut to size. The separator is wrapped around the plates and folded around the mid section, forming a "U" shaped wrap, with one plate in each branch of the "U".

d) The negative plates are covered with a strip of negative interseparator folded as a "U", open at the top and sides.

e) The negative plates (with "U"'s) are placed in the center of the "U" shaped positive wrap, between "U"'s, and at both ends of the cell pack (half end plates).

f) The entire cell pack is wrapped in a "U" strip of C-19 and slipped into the cell case.

5.4.2 Separator Materials.

a) P-3 and P-5 are Yardney code names to designate the positive and negative interseparator materials, consisting of 100% non-woven polyamide fibers. Both are highly calendered. Their physical properties are tabulated below:

	P-3*	P-5
Dry thickness (mils)	2.0-4.0	4.0-7.0
Weight (g/in^2)	0.021-0.023	0.032-0.034
Max. electrolytic resistance** (mohm x in^2)	12	15
Min. electrolyte retention*** (weight %)	200	200

* Tentative specification
** After 1 hour soak in 38% KOH, at 20°C
*** Using 30% KOH

b) The C-19 is a cellophane membrane (300 PUT-0) treated by Yardney C-19 process (proprietary). Physical properties are as follows:

Dry thickness: 1.2 mils max.

Moisture content: 10% min.

Electrolytic resistance: 14 mohm x in^2, max. after 24-hour soak in 45% KOH.

Silver content: 0.7 to 1.3%

Wet thickness: 3.0 - 3.4 mils.

5.5 Electrolyte.

The various concentrations of KOH solutions used for different models of Yardney cells are prepared by diluting 45% solution with the correct amount of distilled water. The 45% solution analysis specifications are as follows (percentages by weight):

KOH	44.0 to 46.0%
K_2CO_3	0.25% max.
KCl	0.01% max.
Fe	0.0005% max.

6 LIST OF SUPPLIERS

Item	Supplier
Silver Powder	Yardney Chemical, Modena, N.Y.
Expanded Metal	Exmet Corp., Tockhoe, N.Y.
Cadmium Oxide Powder	American Smelting & Refining Co., New York, N.Y.
Teflon	E. I. du Pont de Nemours & Co., New York, N. Y.
Pellon (P-3, P-5, P-12)	Pellon Corp., New York, N.Y.
C-19	Yardney Chemical, Modena, N.Y.
Cellophane 300 PUT-0	E. I. du Pont de Nemours & Co.
Silver Wire	Handy and Harman Co., Mt. Vernon, N. Y.
Third Electrodes	American Cyanamide Co., Wallingford, Conn.
Vexar Plastic Netting	E. I. du Pont de Nemours & Co.
KOH	Hooker Chemical Corp., No. Tonawanda, N.Y.

7 CELL PHYSICAL DIMENSIONS

7.1 Weight

7.11 Design for 1.5 hr. orbit

a) Dry, unsealed	:	172 gr.
b) Wet, unsealed	:	228 gr.
c) Potted	:	328 gr.

7.1.2. Design for 8 hr. orbit

a) Dry, unsealed	:	172 gr.
b) Wet, unsealed	:	228 gr.
c) Potted	:	328 gr,

7.1.3 Design for 24 hr. orbit

a) Dry, unsealed	:	184 gr.
b) Wet, unsealed	:	240 gr.
c) Potted	:	340 gr.

Note: All the weights given above have been calculated. While the calculated dry weights should be quite close to the actual cell weights, the wet weights (unsealed and potted) may not be as accurate because the amount of electrolyte cannot be estimated with precision until cell models are built.

7.2 Volume (Same for all designs)

a)	Unsealed, w.o. terminals	:	6.7 in^3
b)	Unsealed, including terminals:	:	7.95 in^3
c)	Potted, w.o. connectors	:	11.75 in^3
d)	Potted, including connectors	:	13.65 in^3

Note: For cell dimensions, see assembly drawings attached to this report.